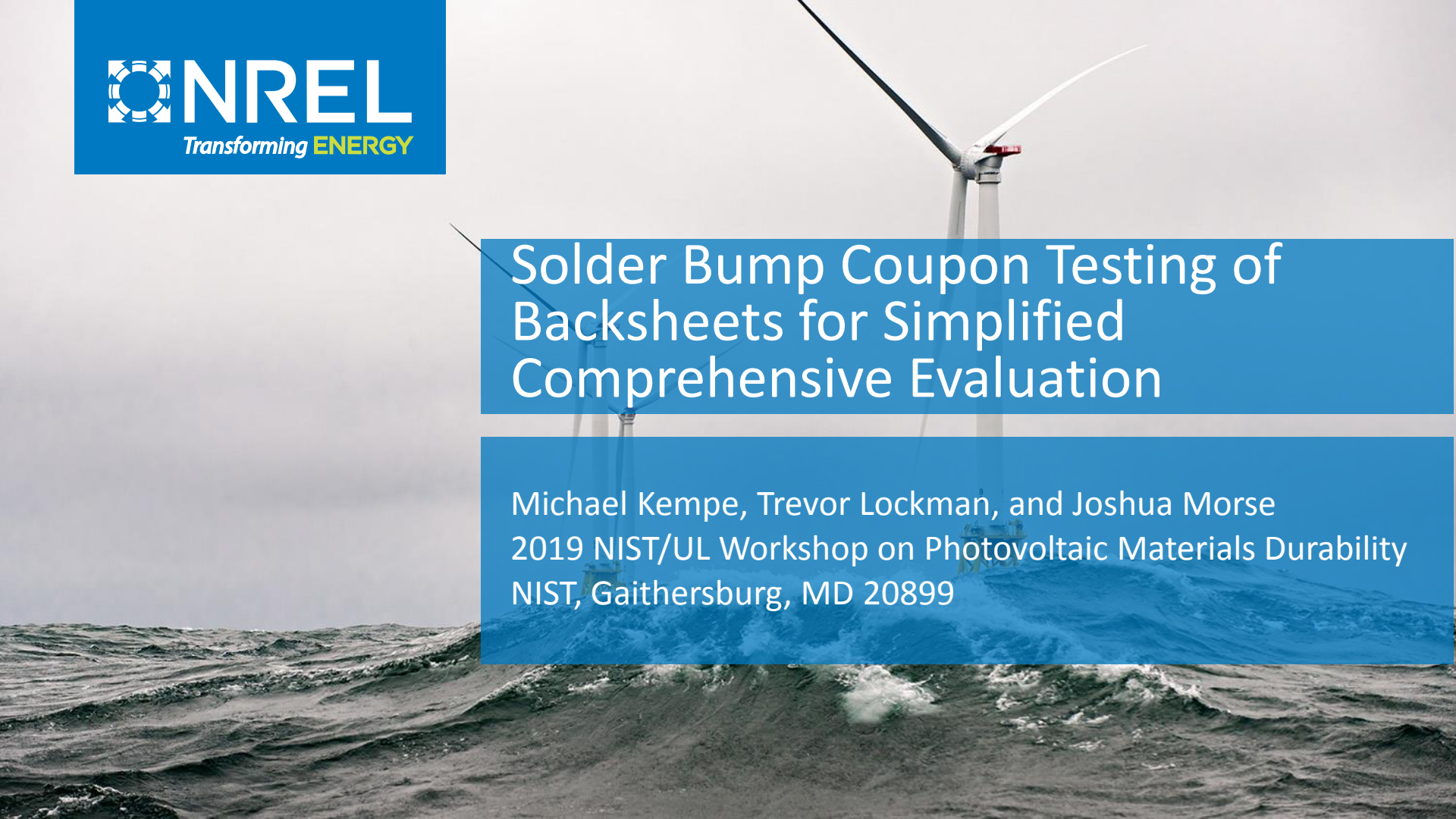


Solder Bump Coupon Testing of Backsheets for Simplified Comprehensive Evaluation

Michael Kempe, Trevor Lockman, and Joshua Morse
2019 NIST/UL Workshop on Photovoltaic Materials Durability
NIST, Gaithersburg, MD 20899

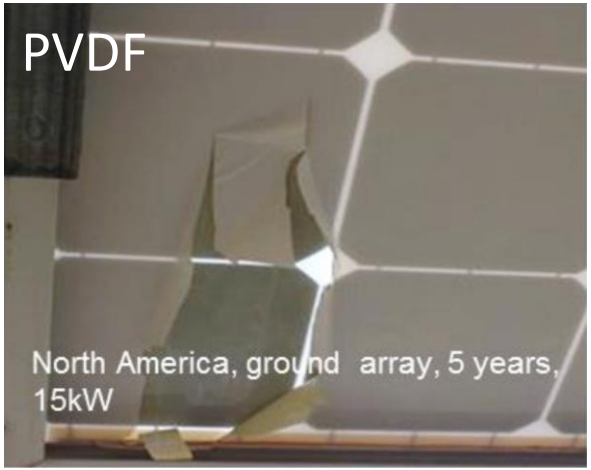
Outline

- Introduction
- Sample geometry development and exposure
- Sample exposure results
- Relevance to standards
- Conclusions
  - Need UV in combination with TC
  - Sample topology is important

Cracks Often Develop in Backsheets

Module Deployed in New Delhi for 4 y (Courtesy of Liang Ji).

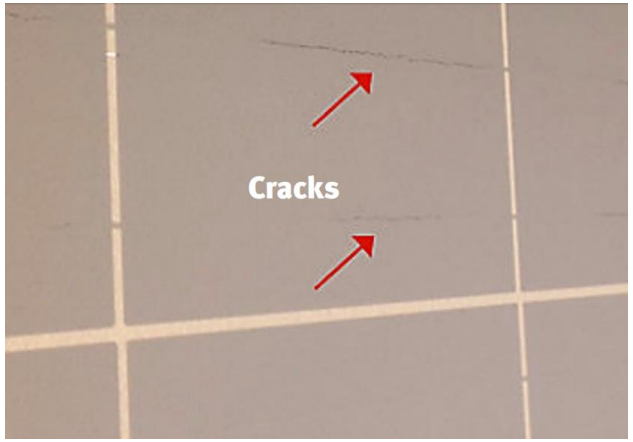
An example of a polyamide backsheet cracking between cells. Other examples show cracks along tabbing. Cracks can appear after as little as 4 to 5 years. Exposed in a Mediterranean climate for 5 y.



*Gambogi et. al Multistress Accelerated Testing and Correlation to Field Performance SNEC 12th (2018) International Photovoltaic Power Generation and Smart Energy Exhibition & Conference

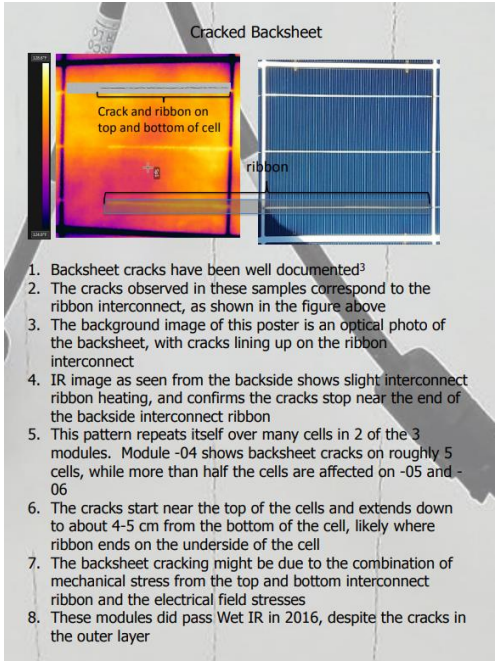
- Current qualification tests will not prevent these failures.
- With increasing cost pressures new materials are being introduced without adequate validation.
- Better testing is needed to provide confidence in new materials

The Polyamide may crack over gaps or between cells



Kaushik Roy Choudhury, William Gambogi, Thomas Felder, Alexander Bradley, Katherine Stika, Steven MacMaster, Lucie Garreau-Iles, Hongjie Hu and T.-John Trout, "Recent Failure of Backsheets in Fielded PV Modules and their Relation to Material Degration", NREL PVRW 2017.

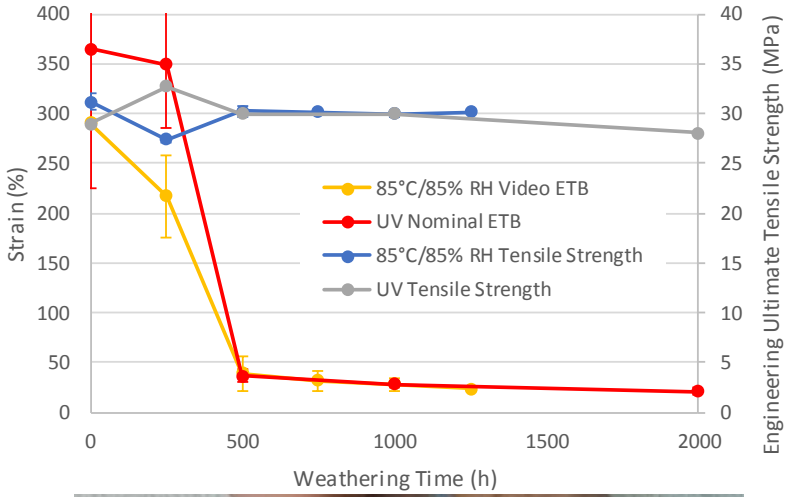
Cracks between cells on module deployed in Rome for 4 y.



Larry Pratt, Cordula Schmid, Cameron Stark, "Multiple Failure Modes on Fielded Glass/mc-Si/polymer Modules", NREL PVRW 2017

Cracks are large and associated with module topology.

Polyamide Physical Changes with Aging



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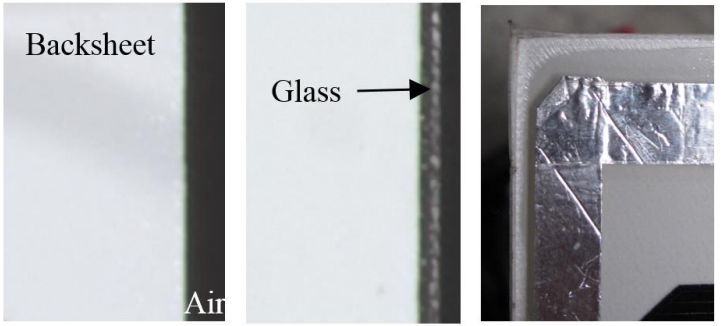


Figure 5: Image of (a) unaged backsheet, (b) aged backsheet with visible displacement of 0.8 mm from the module edge at 4.5 months of test and (c) delamination from edge and corner of module.

- Changes in properties
  - Shrinkage**,***
  - Loss of ETB
- However
  - Maximum tensile stress is essentially unchanged
  - Did not crack in a bend test.
  - Free standing films don't crack.

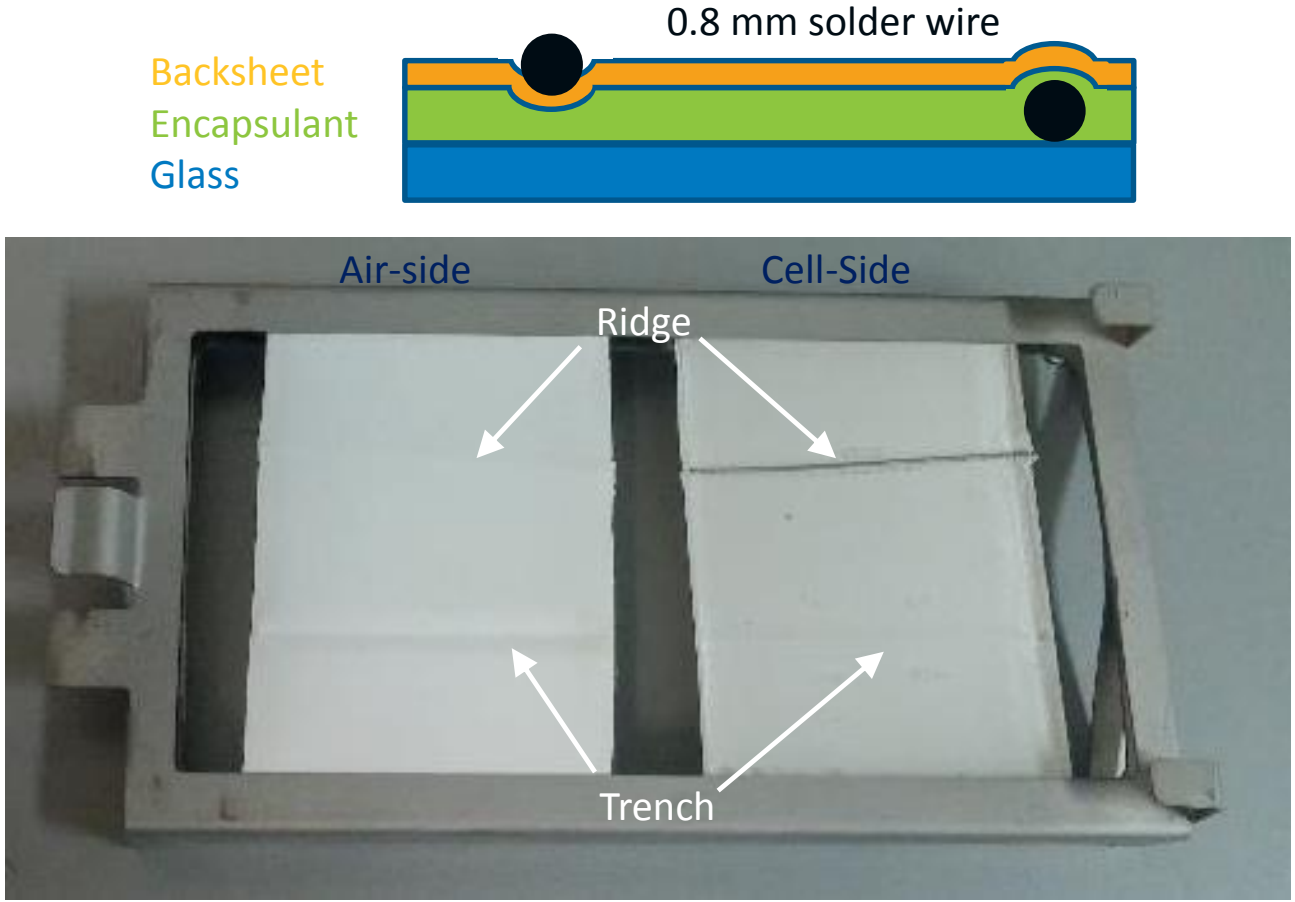
* Michael D. Kempe, David C. Miller, Allen Zielnik, Daniel Montiel-Chicharro, Jiang Zhu, Ralph Gottschalg, "Survey of Mechanical Durability of PV Backsheets", IEEE PVSC (2017)

** Michael Owen-Bellini, Peter Hacke, Sergiu Spataru, David C. Miller, Michael Kempe, "Combined-accelerated stress testing for advanced reliability assessment of photovoltaic modules", EUPVSEC 2018.

*** Gabriele C. Eder, Yuliya Voronko a, Gernot Oreski, Wolfgang Mühleisen, Marlene Knausz, Antonia Omazic, Alois Rainer, Christina Hirschl, Horst Sonnleitner, "Error analysis of aged modules with cracked polyamide backsheets", Solar Energy Mterials & Solar Cells 203 (2019) 110194

Laminated test samples to duplicate module contours

Because cracks appear along surface contours of a module, samples were laminated with a solder wire to produce “ridges” and “trenches.

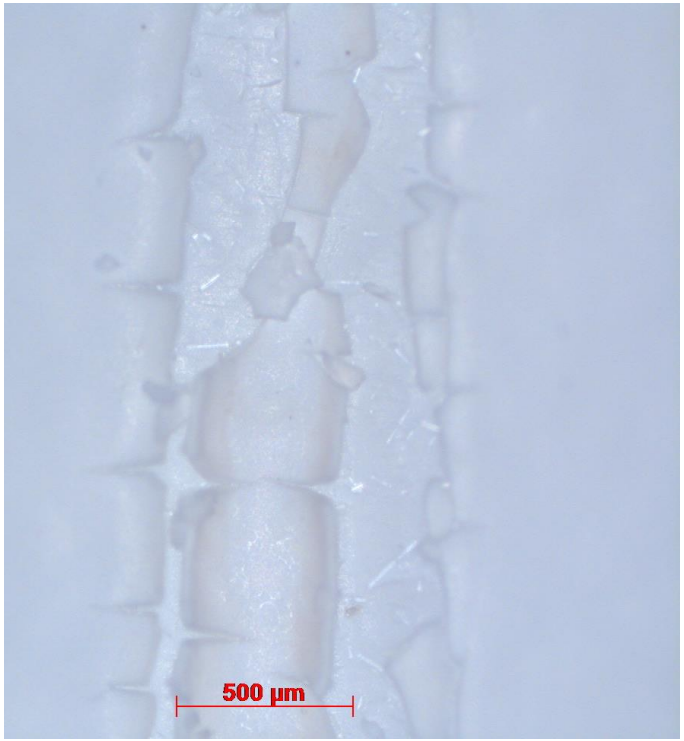


Exposure Conditions and Materials

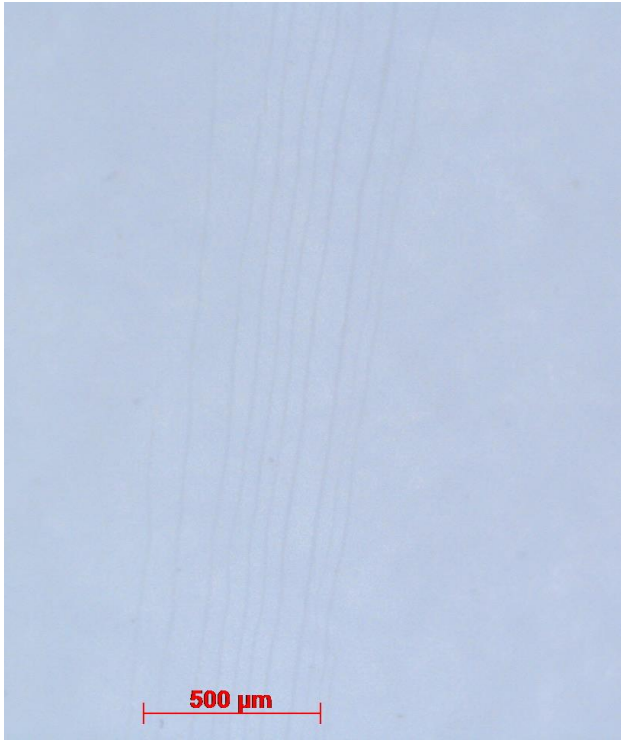
- UV Exposure
  - Condition A3 of 62788-7-2.
  - 0.8 W/m²/nm @340 nm, CAT=65°C, BPT=90°C, 20% RH.
- Thermal cycling (TC)
  - IEC 61730-2(2016) MST 51.
  - -40°C to 85°C about 8 times per day.
- Backsheet Test Samples
  - Polyamide
  - PPE
  - PVDF/P/"E"
  - Samples are being exposed to:
    - 4000 h UV then 600 TC.
    - 4000 h UV + spray.
    - 500 h UV/100 TC – Repeated 5 times.
    - 500 h DH/100 TC – Repeated 5 times.
- Second Material set
  - 11 materials tested
    - 1 PPE
    - 5 TPE
    - 1 PVDF/PET/"E"
    - 2 Fluoropolymer/PET/"E"
    - 1 PO/PP/E
    - 1 PO/PA/PP/E
  - 4000 h UV and 600 TC.

PA only cracked in the outer layer with just UV/heat/humidity

Trench



Ridge



Side view of film

PA + PP + Fiberglass core

PA

PA

Photos from 2500 h exposure of UV with air-side exposure.
Even after 4000 h the cracks were only in the outer PA layer.

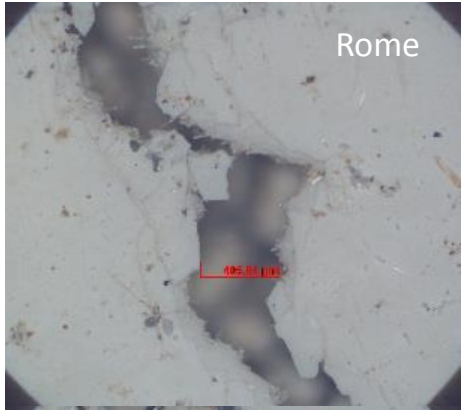
Polyamide Failure in the chamber is similar to outdoor

Indoor Exposure in UV condition
0.8 W/m²/nm, 65°C, 20% RH

5 y Field Exposure, Rome, Italy

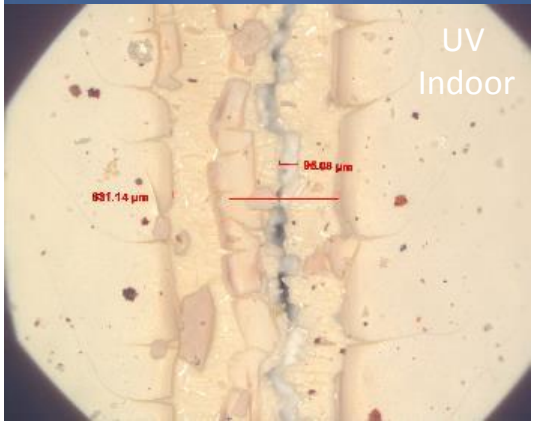
4000 h UV
& 200 TC

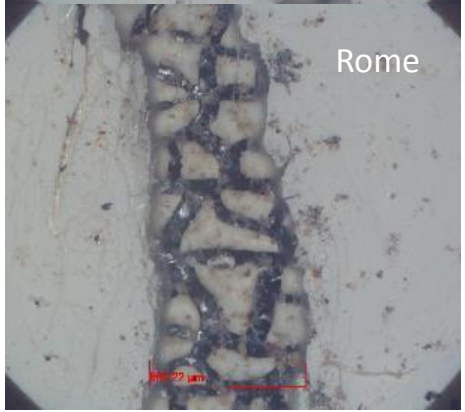
Cell-Side
Exposure



4000 h UV
& 400 TC

Air-Side
Exposure





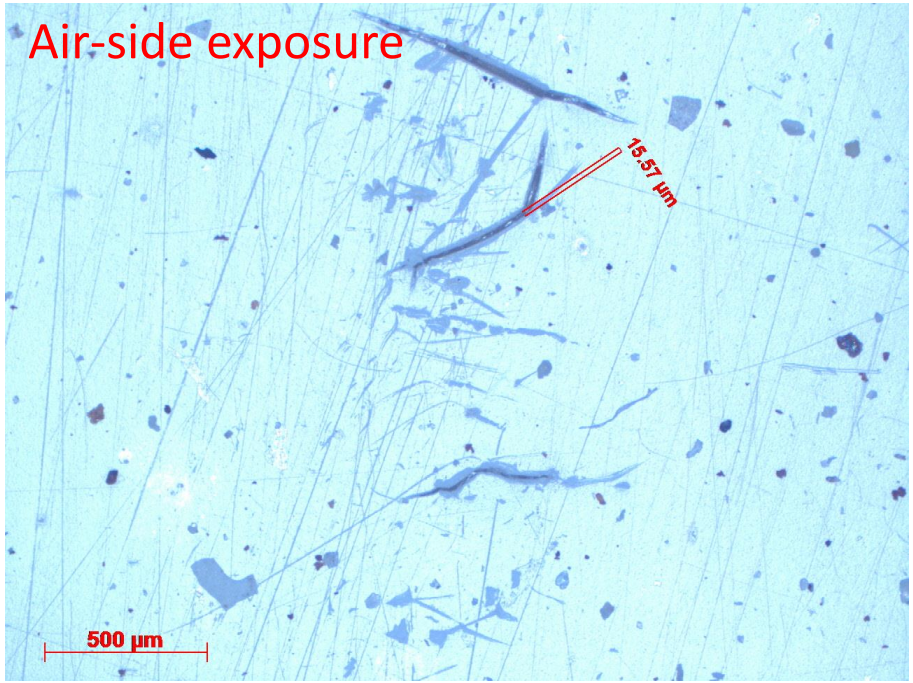
More Cracking with Cell-Side Exposure to A3

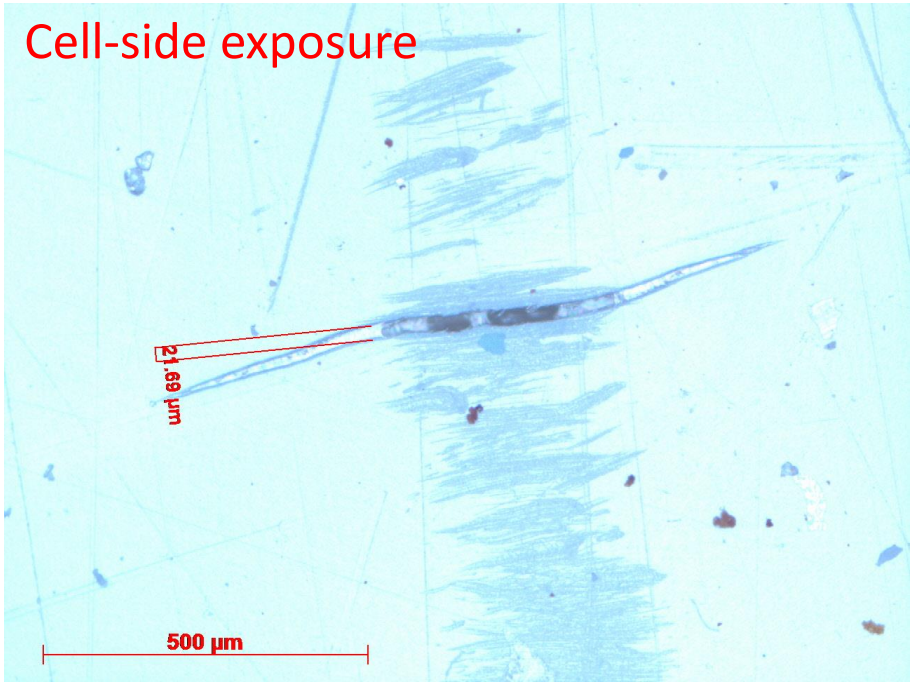
Larger cracks are seen with exposure from the cells side through UV filter EVA. The air-exposed side has more discoloration but much smaller cracks.

Cracks appear best where the inside surface of the backsheet is curved and in tension.

Either the inner polyamide surface is not stabilized the same as the outer surface, or there is a specific interaction with EVA.

PVDF Also showed cracking failure.



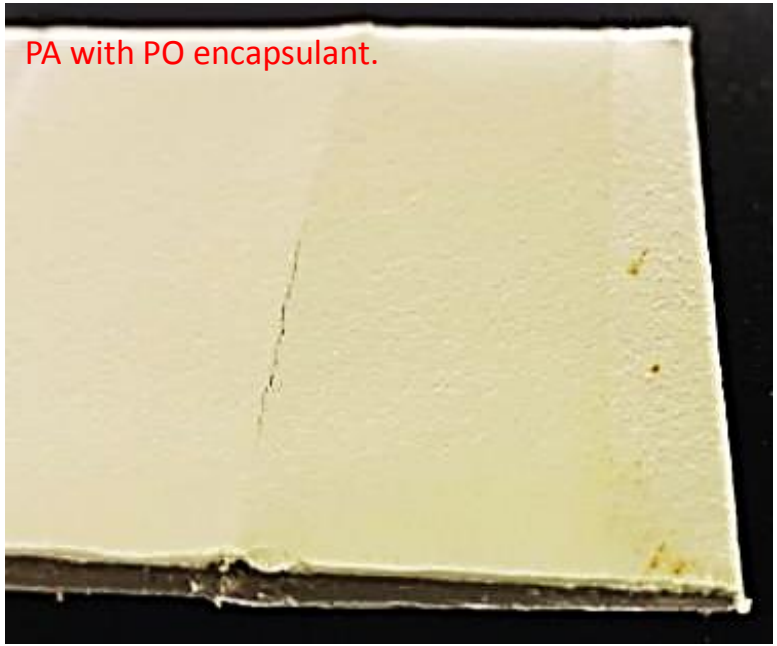


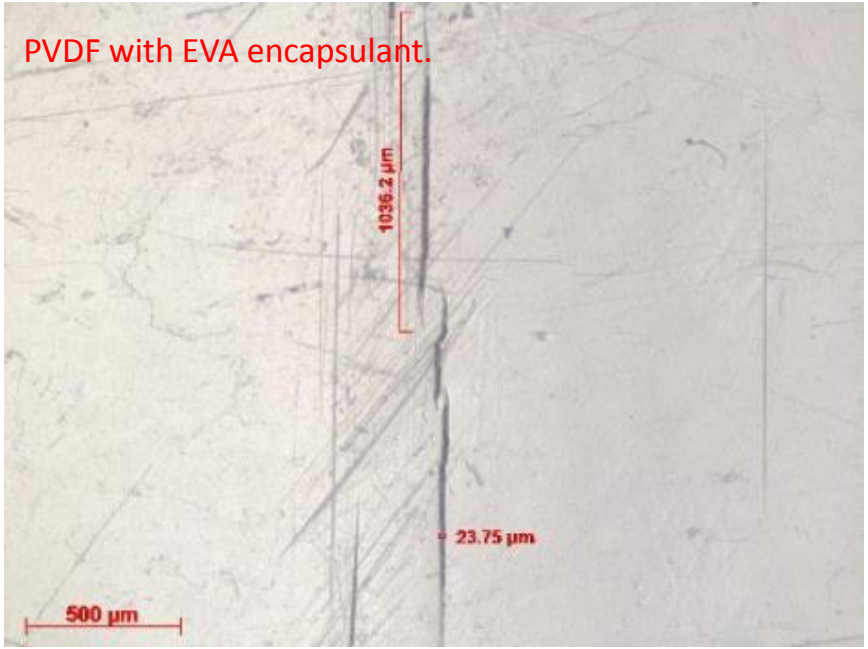
PVDF, Ridge area, after 4000 h UV and 200 TC.

Some PVDF-based backsheets are known to fail in the field. PVDFs have a very high preference for failure with cracks in the MD which runs counter to the typical condition of extra residual strain in the MD which should favor cracks in the TD. One possible explanation for this is their unique crystalline structure.

500 h UV and 100 TC Causes Cracking

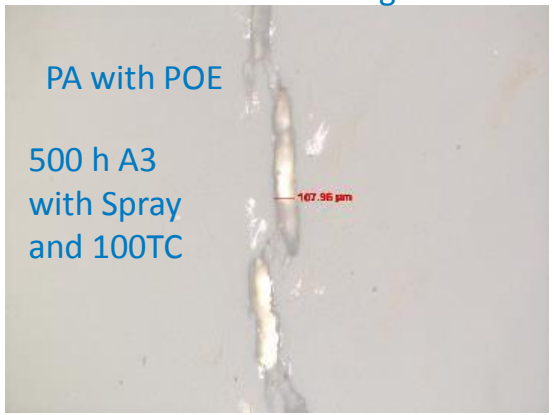
- After 500 h UV and 100 TC.
  - PVDF – Cracks on cell-side exposed samples only.
  - PA – Cracks on air-side exposed samples for both PO and EVA encapsulant.
- After 2500h UV and 500TC
  - PA and PVDF show cracks with exposure to either side
  - PPE shows only surface cracking and some erosion/chalking.

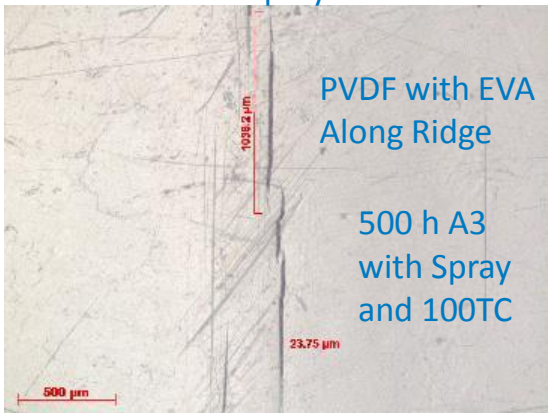


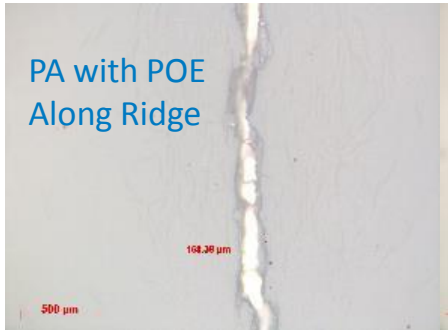


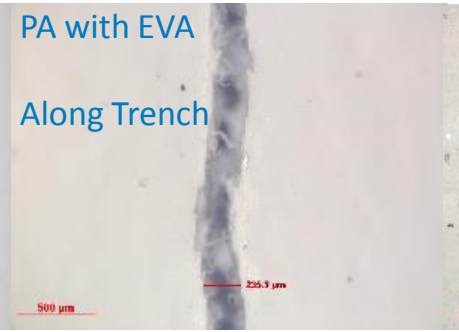
500 h A3 with Spray and 100 TC

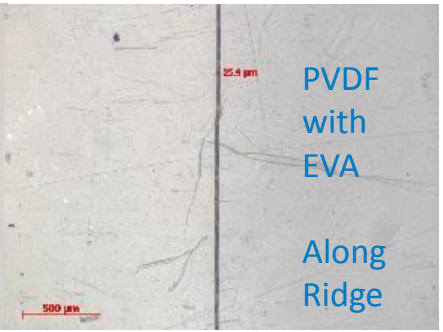
After 2000 h/400TC the addition of spray only serves to increase the amount of erosion on the surfaces. The Cracking tendencies are the same as without spray.







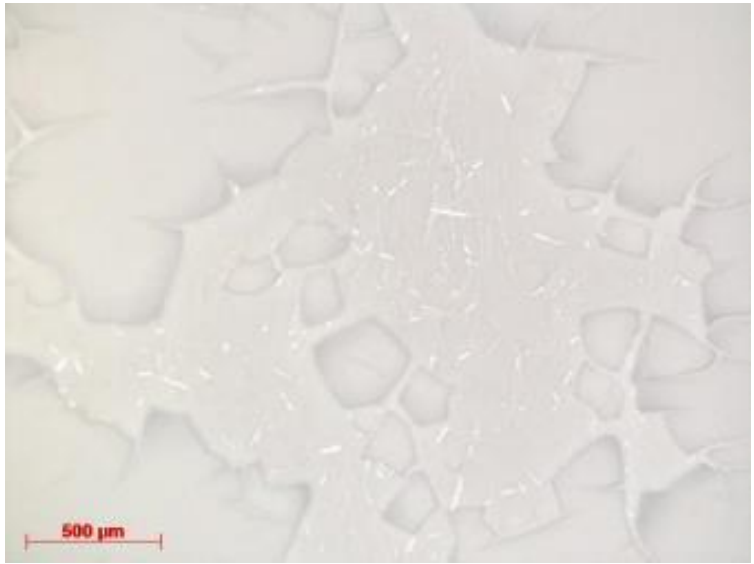




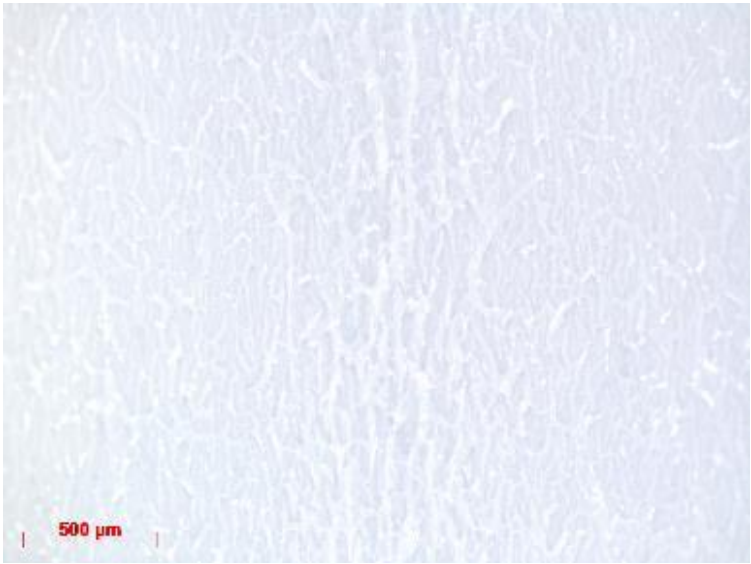
1000 h A3 with Spray and 200TC

UV with Spray, no TC, did NOT produce large cracks

- After completing the total of 4000 h of UV with spray:
  - Neither the PPE, PVDF, or PA produced any cracks along the ridge or trench.
  - The PA showed nearly complete erosion of the outer layer



1500 h Exposure, only surface PA film removed, No cracks



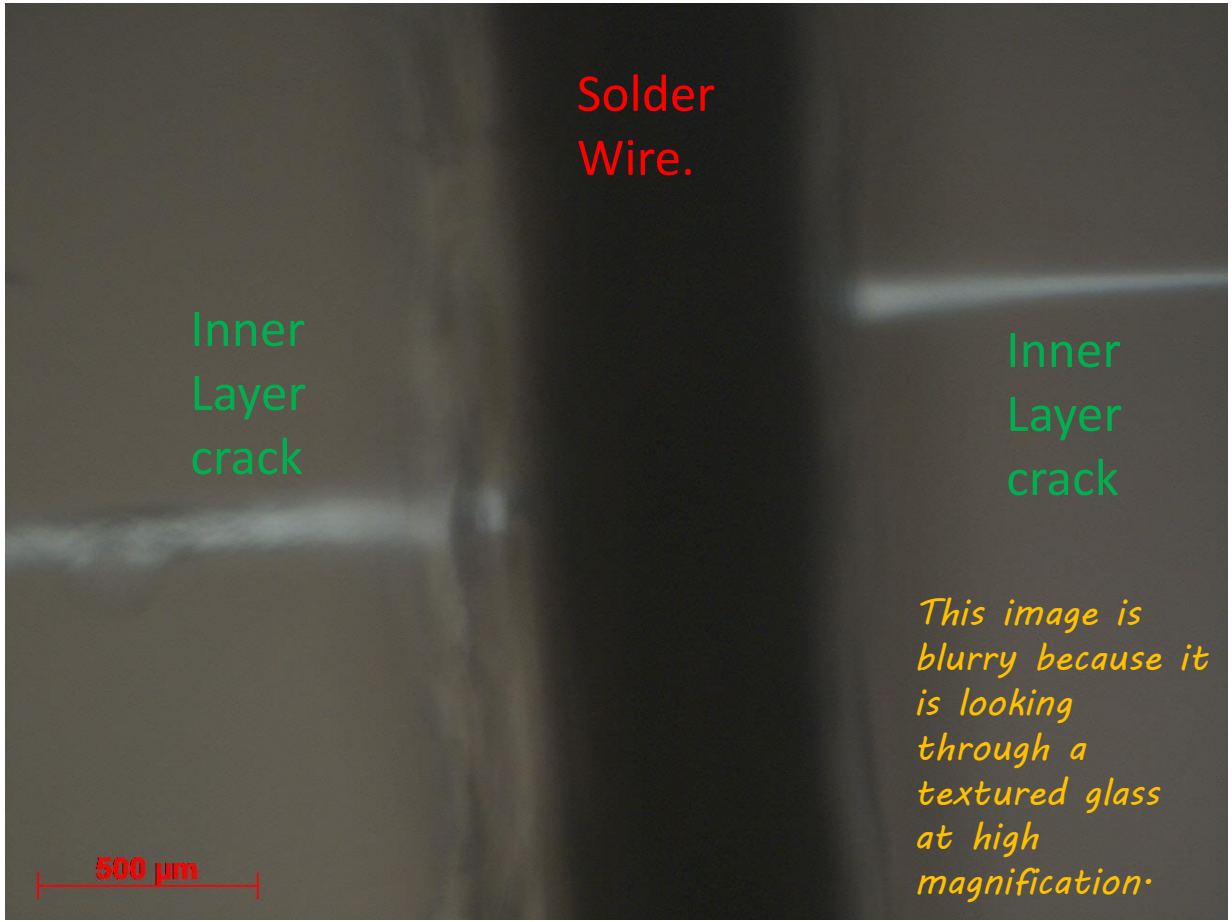
4000 h Exposure. Ridge area. Primarily surface PA film removed. Cracks only through outer PA surface.

In UV with Spray and no TC material showed inner layer cracks

PPE film 4000 h Exposure UV with spray. This demonstrates the ability of this test to also crack an inner layer.

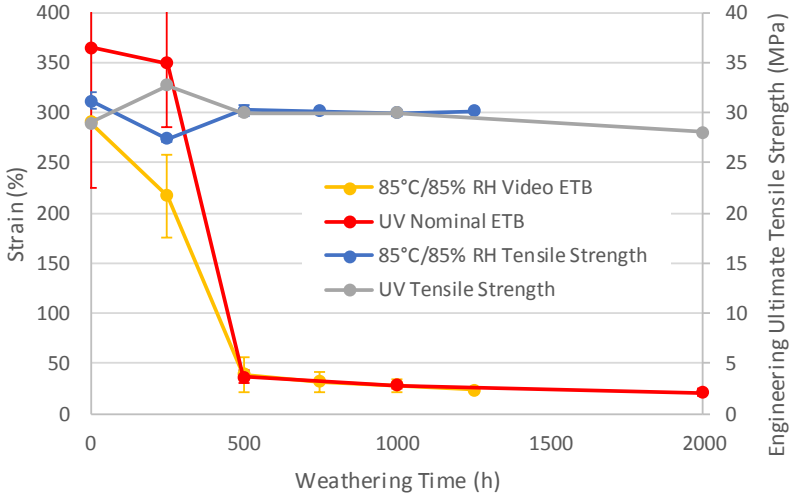
Backlit looking from Glass side where a solder wire under a ridge is visible along with inner layer cracks.

Cell-Side exposure using UV blocking EVA.

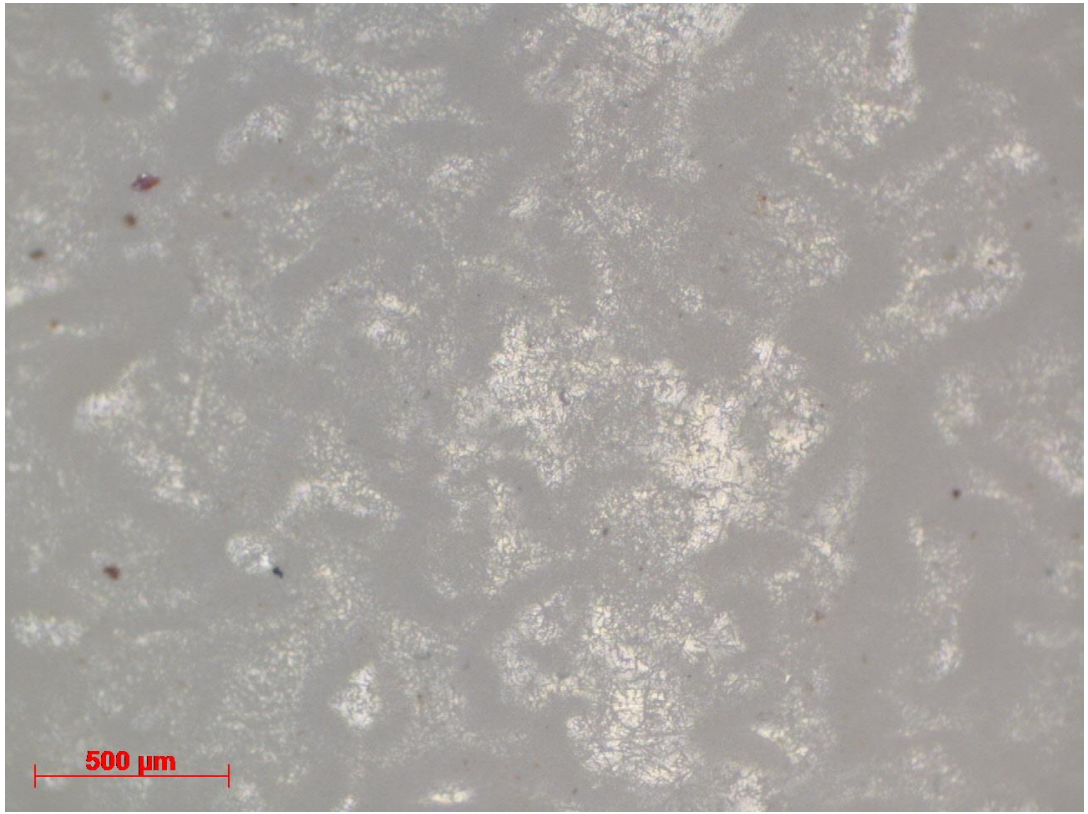


Damp heat followed by TC did not Crack AAA

- Damp heat is not sufficient to cause cracking quickly, UV light seems to be needed for cracks all the way through the PA backsheet in an amount of time representative of outdoor exposure.



PA, Ridge Area after 2500 h Damp Heat and 500 TC.



Additional Films exposed to 4000 h UV followed by 600 TC

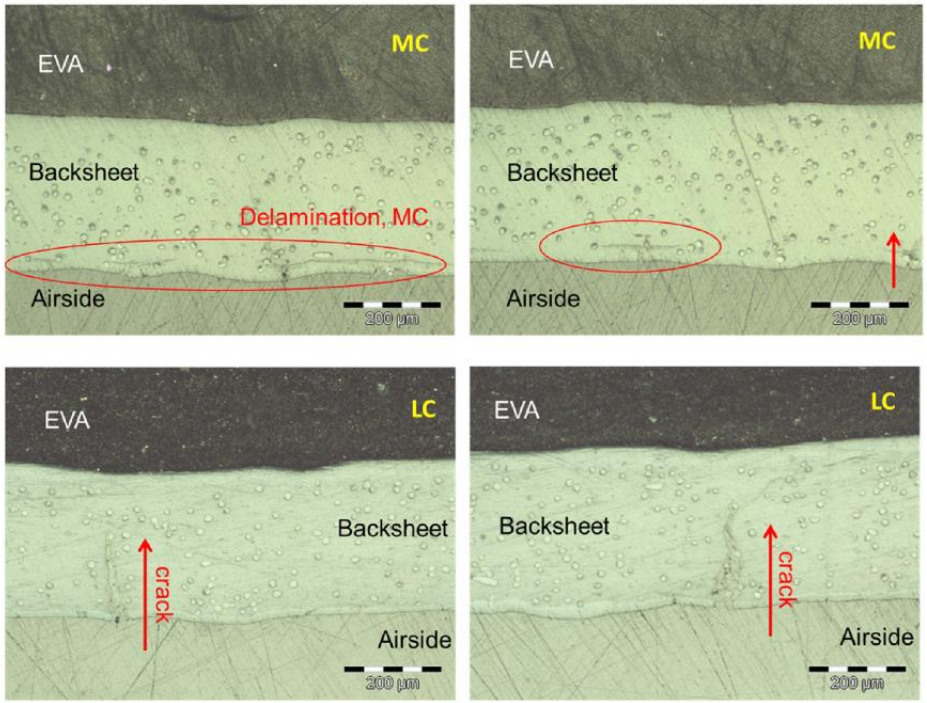
- 11 materials tested
  - No cracks all the way through:
    - 1 PPE
    - 5 TPE
    - 2 Fluoropolymer/PET/"E"
  - The PVDF film showed cracks in the MD predominantly on the UV side and near the ridge or trench. Cracking only seen after TC.
    - 1 PVDF/PET/"E"
  - Two PO based backsheets showed some surface cracking predominantly near the ridge but not until after TC.
    - 1 PO/PA/PP/E
    - 1 PO/PA/PP/E

PPE after 4000 h UV and 600 TC. Ridge

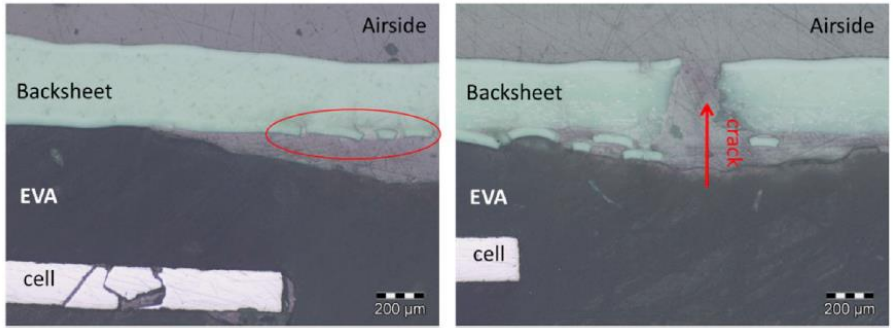
PO/PA/PP/E after 4000 h UV and 400 TC

Other Researchers see UV Enhancement too

Module with Dispersed Microcracks or Longitudinal Cracks over Tabbing



Module with Cracks between Cells

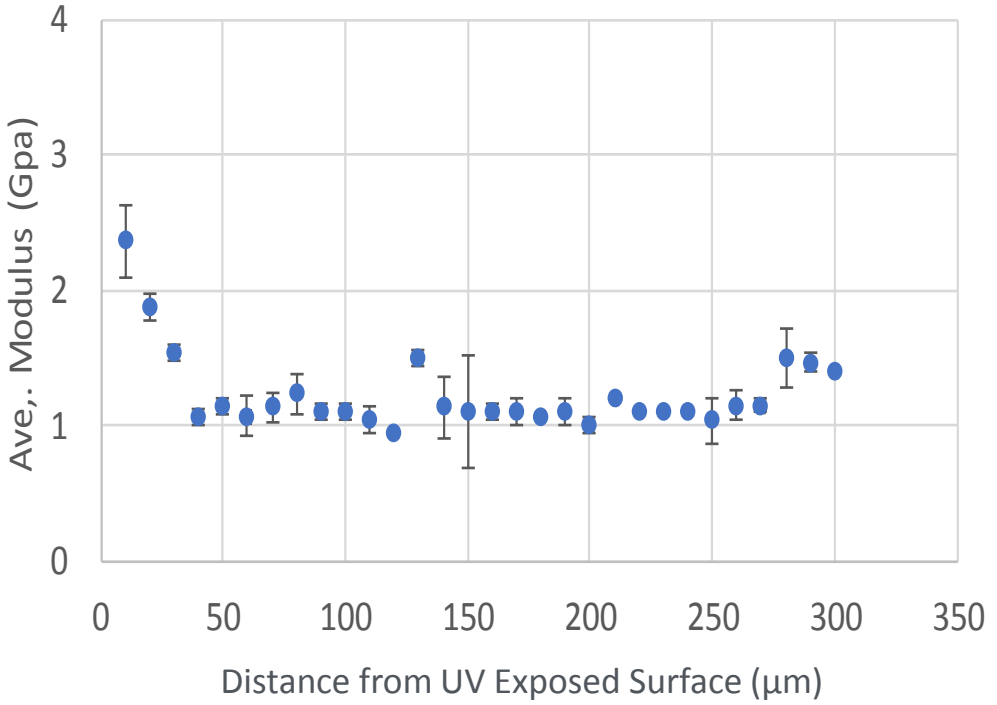


UV light was seen to affect the side in which cracks were initiated.
For cracks between cells, UV light is a key driving stress.
Similarly saw EVA enhancement of cracks.

Gabriele C. Eder, Yuliya Voronko a, Gernot Oreski, Wolfgang Mühleisen, Marlene Knausz, Antonia Omazic, Alois Rainer, Christina Hirschl, Horst Sonnleitner, “Error analysis of aged modules with cracked polyamide backsheets”, Solar Energy Mterials & Solar Cells 203 (2019) 110194

Nano-Indentation Shows Embrittlement of the Surface

- The UV exposed side creates a region of high modulus in one of the PA outer layers.
- This allows for thermo-mechanical stress to initiate a crack after which the stress concentration at the crack tip in combination with more thermo-mechanical stress will propagate the crack all the way through the backsheet.

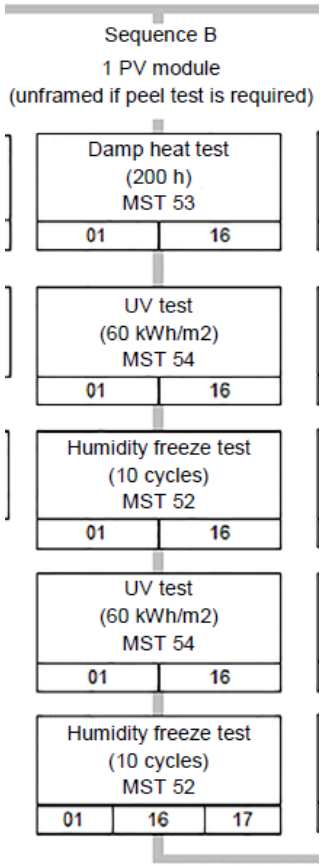


4000 h of UV exposure under A3 conditions
(0.8 W/m²/nm @340 nm, CAT 65°C, 20% RH, BPT 90°C)

Michael D. Kempe, Yadong Lyu, Jae Hyun Kim, Thomas Felder, Xiaohong Gu "Fragmentation of Photovoltaic Backsheets after Accelerated Weathering Exposure", To be Published.

Working on Incorporating TC into IEC 63209 Extended Module Testing

- IEC 63209, EXTENDED STRESS TESTING OF PHOTOVOLTAIC MODULES
- Intended to unify the testing of modules beyond IEC 61215 and IEC 61730 to a uniform set of testing procedures and protocols to minimize the testing burden while improving its relevance.
- Currently the discussion of the extension of Sequence B from IEC 61730 to more cycles is hotly debated and the topic of an interlaboratory experiment. It is being proposed to add TC after UV exposure in place of HF to catch these sorts of UV induced thermal mechanical weaknesses.



IEC 61730-1 (2016)

63209 proposal are based of 61730 and other test sequences

MAST	PVEL's backsheet durability sequence	PVEL's faster BDS	C450 and IEC 61730:2016	TUV - Rheinland	63209 - 3b (baseline)	63209 - 3b (extended)	63209 - 3b (DH1000)
				One front, one back			
DH1000	DH1000	DH200	DH200	DH200	DH200	DH200	DH1000
UV 65kWh/m2 at 150W/m2 and 70°C BPT	UV 65kWh/m2 at 150W/m2 and 80°C BPT	UV 65kWh/m2 at 150W/m2 and 80°C BPT	UV - Front side 60kWh/m2 at 60°C BPT	UV 60kWh/m2 at 60°C BPT	UV 60kWh/m2	UV 60kWh/m2	UV 60kWh/m2
TC200	TC50+HF10	TC50+HF10	HF10	HF10	HF10	HF10	HF10
UV	UV	UV	UV - rear side	UV	UV	UV	UV
TC200	TC50+HF10	TC50+HF10	HF10	HF10	TC200?	TC200?	TC200?
UV	UV	UV		TC200		UV	UV
TC200	TC50+HF10	TC50+HF10				TC200?	TC200?
UV 6.5 kWh/m2	UV 6.5 kWh/m2	UV 6.5 kWh/m2					

Conclusion for Solder Bump Test

- Developed a chamber-based test to reproduce cracking of backsheets.
  - Can show cracks in inner layers too.
- UV light highly involved in PA cracking.
  - For the polyamide damp heat is at the very least much less effective at producing cracks.
- Thermal cycling is needed to reproduce cracking.
  - The addition of a spray cycle to UV exposure increased erosion rates but did not induce cracking without TC.
- Working to incorporate this knowledge into IEC standards